Nanomaterials and its properties, Classifications of nano materials

Outlines:

1. Introduction of nanomaterials
2. Different properties of nano materials
3. Classifications of nano materials

Prerequisite/Recapitulations

Three-dimensional (3D) structure or bulk structure: No quantization of the particle motion occurs, i.e., the particle is free.

Two-dimensional (2D) structure or quantum well : Quantization of the particle motion occurs in one direction, while the particle is free to move in the other two directions.

One-dimensional (1D) structure or quantum wire (Nano wires): Quantization occurs in two directions, leading to free movement along only one direction.

Zero-dimensional (0D) structure or quantum dot (sometimes called "quantum box"): Quantization occurs in all three directions

Objectives

After the completion of this lecture, you will be able to:

1. Explain the nanomaterials
2. Learn the different properties of nano materials
3. Classify the nano materials

Conceptualization

Introduction

Definition of Nanotechnology

"Nanotechnology is the understanding and control of matter at dimensions of roughly 1 to 100 nanometers, where unique phenomena enable novel applications."

"Encompassing nanoscale science, engineering and technology, nanotechnology involves imaging, measuring, modeling, and manipulating matter at this length scale."

Birth of Nanotechnology

- Professor Taniguchi of Tokyo Science University used the word "nanotechnology" to describe the science and technology of processing or building parts with nanometric tolerances.
- A nanometer is a unit of length in the metric system, equal to one billionth of a meter.

1 nanometer =	
1×10^{-9}	meter
1×10^{-3}	µm
3.281×10^{-9}	feet
39.37×10^{-9}	inches

Dr. Feynman: *"The problems of chemistry and biology can be greatly helped if our ability to see what we are doing, and to do things on an atomic level, is ultimately developed – a development which I think cannot be avoided."*

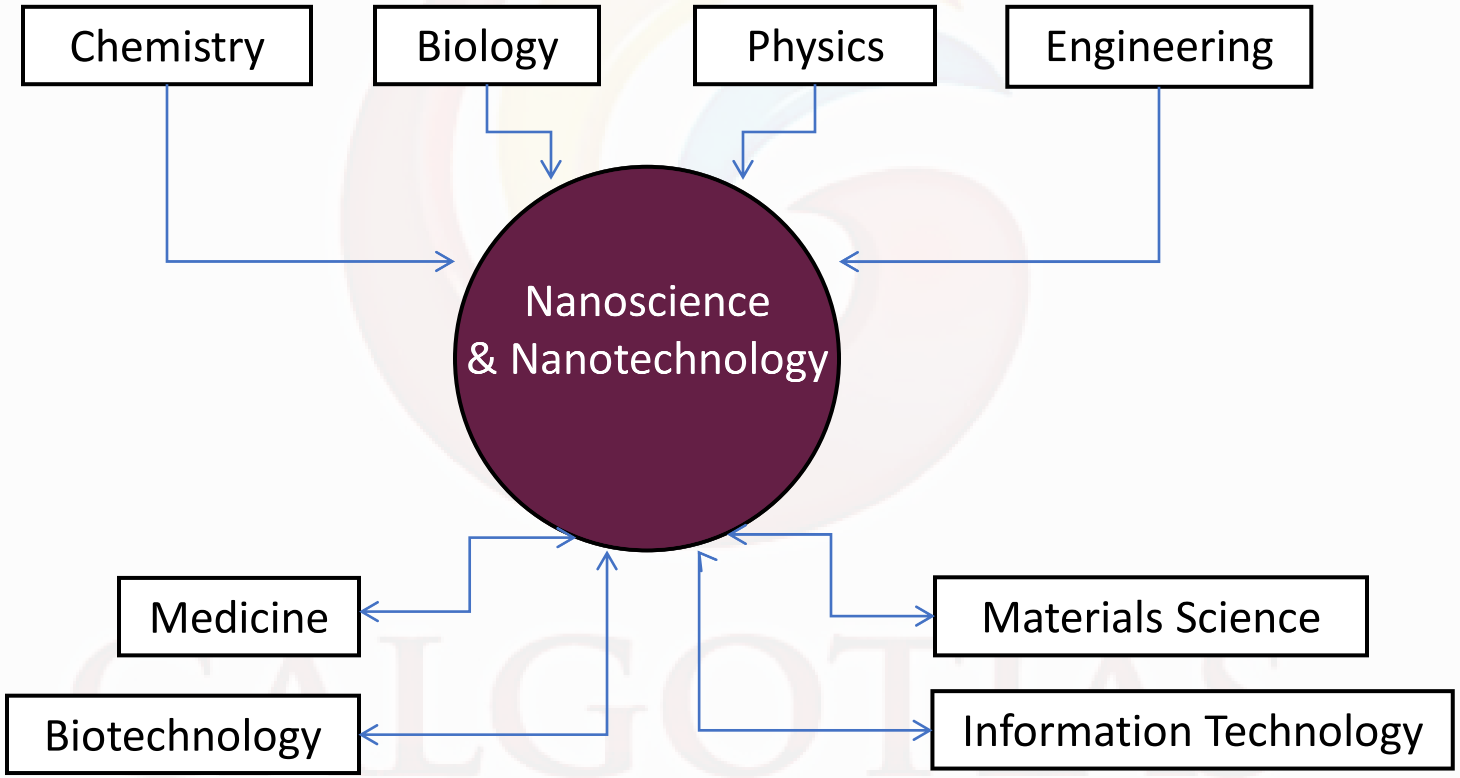
Introduction

Nanotechnology is an emerging field in all areas of science, engineering and technology.

Key ideas:

1. The nanometer is extremely small.
2. At the nanometer scale, materials may behave differently.
3. We can harness this new behavior to make new technologies.

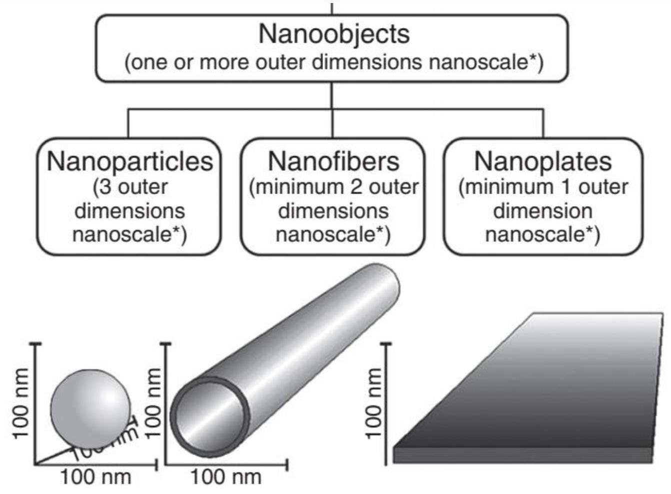
Nanoscience-An Interdisciplinary Endeavor



Nanomaterials and its properties

Nanomaterials are conventionally defined as materials having at least a dimension between 1 and 100 nm. As a consequence, nanoparticles have all the three dimensions in the nanometer range, nanoplates present only one dimension below 100 nm, whereas nanofibers have two dimensions in the range of nano being the remaining remarkably longer.

100 nm as an upper limit for a nanomaterial is not always accepted. Many organizations in the world fixed different thresholds for the nanoscale, although 100 nm still remains the most common shared limit.



Current definitions of terms with the "nano" suffix.

Type	Description
Nanoscale	Size range from approximately 1–100 nm
Nano-object	Material with one, two, or three external dimensions in the nanoscale
Nanoparticle	Nano-object with all three external dimensions in the nanoscale
Nanotemplate	Nano-object with one external dimension in the nanoscale and the other two external dimensions significantly larger (at least three times)
Nanofiber	Nano-object (flexible or rigid) with two external dimensions in the nanoscale and the third dimension significantly larger
Nanotube	Hollow nanofiber
Nanorod	Solid nanofiber
Nanowire	Electrically conducting or semiconducting nanofiber

Properties: SIZE DEPENDENT PROPERTIES OF NANOMATERIALS

The various properties, which get tremendously altered due to the size reduction in at least one dimension are:

a) Chemical properties: Reactivity; Catalysis. b) Thermal property: Melting point temperature. c) Electronic properties: Electrical conduction. d) Optical properties: Absorption and scattering of light. e) Magnetic properties: Magnetization.

A. Chemical Properties

Based on the surface area to volume effect, nanoscale materials have:

a) Increased total surface area.

b) Increased number of atoms accessible on the surface.

c) Increased catalytic activity of those large number surface atoms.

d) Different/tunable surface catalytic properties by the change in shape, size and composition.

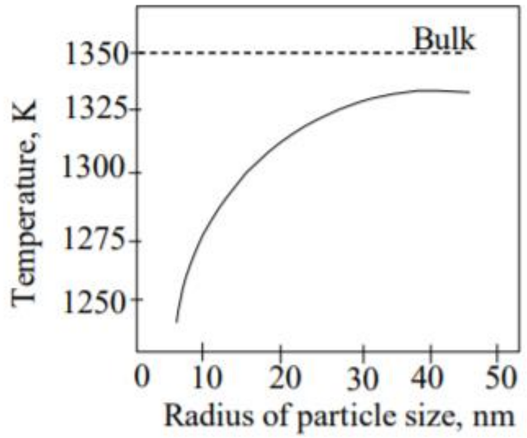
Hence, nanoscale catalysts can increase the rate, selectivity and efficiency of various chemical reactions.

Nano materials and its properties

Properties: SIZE DEPENDENT PROPERTIES OF NANOMATERIALS

B. **Thermal Properties**

The melting point of a material directly correlates with the bond strength. In bulk materials, the surface to volume ratio is small and hence the surface effects can be neglected. However, in nanomaterials the melting temperature is size dependent and it decreases with the decrease particle size diameters.



The reason is that in nanoscale materials, surface atoms are not bonded in direction normal to the surface plane and hence the surface atoms will have more freedom to move.

Properties: SIZE DEPENDENT PROPERTIES OF NANOMATERIALS

C. **Electronic Properties**

- In bulk materials, conduction of electrons is delocalized, that is, electrons can move freely in all directions.
- When the scale is reduced to nanoscale, the quantum effect dominates. For zero dimensional nanomaterials, all the dimensions are at the nanoscale and hence the electrons are confined in 3-D space. Therefore no electron delocalization (freedom to move) occurs.
- For one dimensional nanomaterials, electrons confinement occurs in 2-D space and hence electron delocalization takes place along the axis of nanotubes/nanorods/nanowires.
- Due to electron confinement, the energy bands are replaced by discrete energy states which make the conducting materials to behave like either semiconductors or insulators.

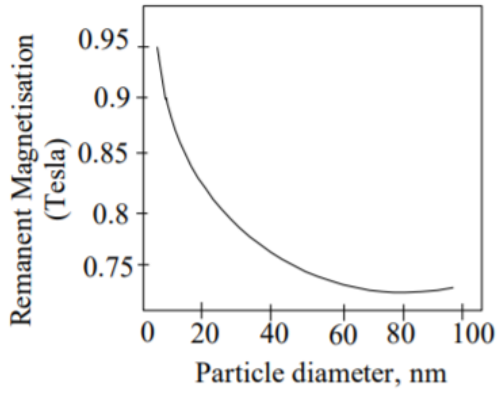
Properties: SIZE DEPENDENT PROPERTIES OF NANOMATERIALS

D. **Optical Properties**

Because of the quantum confinement in nanomaterials, the emission of visible light can be tuned by varying the nanoscale dimensions. It is observed that the size reduction in nanomaterials shifts the emission of peak towards the shorter wavelength (blue shift).

E. **Magnetic Properties**

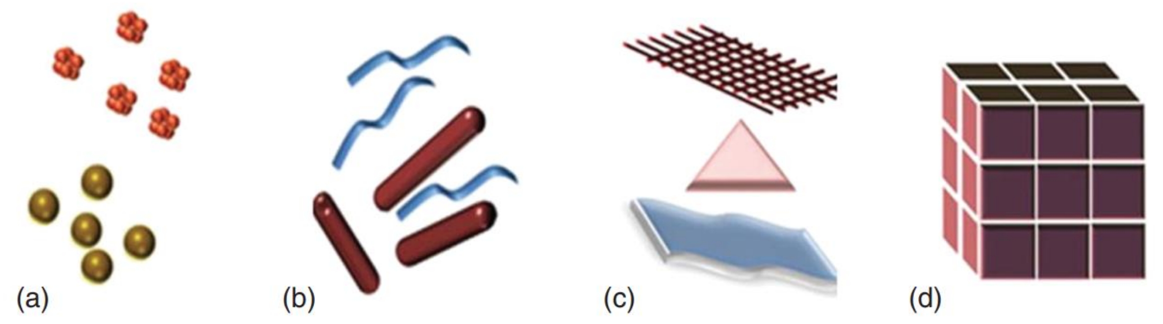
The size of magnetic nanoparticles also influences the value magnetization. The figure illustrates the effect of particle size on the saturation magnetization of zinc ferrite. The magnetization increases significantly below a grain size of 20nm. Hence, by decreasing the particle size of a granular magnetic material it is possible to improve the quality of magnets fabricated from it.



Classification of nanomaterials

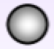
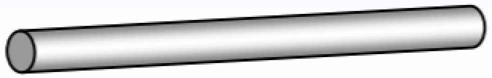
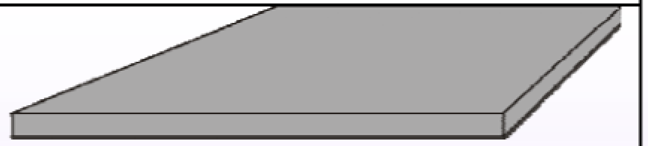
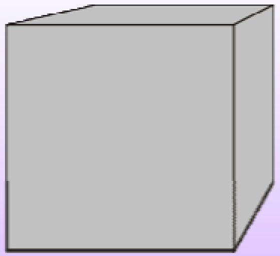
On the basis of reduction in size of materials in different dimensions, nanomaterials are classified into three groups.

S. No.	Reduction in size in different coordinates	Size	Examples
1.	3-dimensions	< 100 nm	Nanoparticles, quantum dots
2.	2-dimensions	< 100 nm	Nanotubes, nanowires, nanofibers
3.	1-dimension	< 100 nm	Thin films, coatings



Classification of nanomaterials (a) 0D spheres and clusters; (b) 1D nanofibers, wires, and rods; (c) 2D films, plates, and networks; and (d) 3D nanomaterials

Classification of nanomaterials

Number of nanosized dimensions nano-D = nD	Number of bulk dimensions (D)	Example	
3 *(Nanoparticles, nanocrystals)*	0	Nanocrystals of gold	
2 *(Nanowires, nanorods, nanotubes)*	1	Carbon nanotube	
1 *(Nanolayers, nanofilms)*	2	SiGe epitaxial layer on Si substrate	
0	3	Bulk single crystal of silicon	

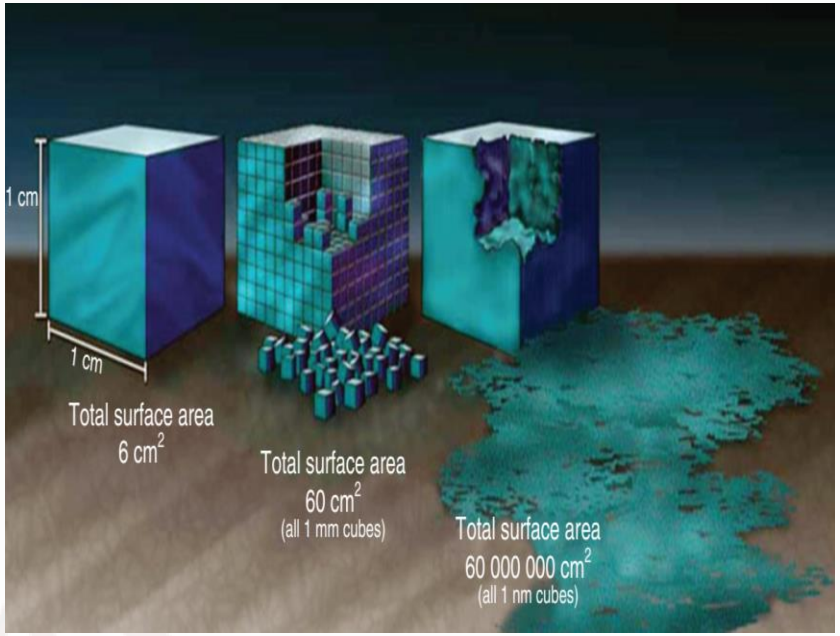
Applications of Nanoparticles

a) Silver nanoparticles have good antibacterial properties, and are used in surgical instruments, refrigerators, air-conditioners, water purifiers etc.
b) b) Gold nanoparticles are used in catalytic synthesis of silicon nano wires, sensors carrying the drugs and in the detection of tumors.
c) ZnO nanoparticles are used in electronics, ultraviolet (UV) light emitters, piezoelectric devices and chemical sensors.
d) TiO2 nanoparticles are used as photocatalyst and sunscreen cosmetics (UV blocking pigment).
e) Antimony-Tin-Oxide (ATO), Indium-Tin-Oxide (ITO) nanoparticles are used in car windows, liquid crystal displays and in solar cell preparations.

Problem

Question: When dealing with nanomaterials , the dramatic enhancement of the surface area with decreasing object dimensions. Explain it.

Let us assume an experiment in which a cube of 1 cm on a side is progressively reduced in a collection of smaller cubic particles, keeping the total mass constant. The starting cube has a total surface area of 6 cm^2. In the second step, the initial cube is decomposed into cubes of 1 mm on a side. The overall number of such cubes is 10^3. The overall surface can be calculated as (6 mm^2/object × 10^3 objects) = 60 cm^2. In a third step of the virtual experiment, the cube of 1 cm on a side is decomposed into cubes of 1 µm on a side. As 1 cm = 10^4 µm, the total number of little cubes is now $(10^4)^3 = 10^{12}$ cubes. The overall surface area is now 6×10^{12} μm^2, corresponding to 6 m^2. The final step is getting to the Nano dimension. As 1 nm = 10^{-9} m = 10^{-7} cm, the calculation shown above leads to the astonishing numbers of 10^{21} little cubes, each accounting for a surface of 6 nm^2. The sum of surface areas is 6×10^{21} nm^2, i.e. 6 km^2



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